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Abstract - We report on the performance of an S-band RF photocathode electron gun and accelerator for operation with the PLEIADES Thomson x-ray source at LLNL. To produce picosecond, high brightness x-ray pulses, picosecond timing, terahertz bandwidth diagnostics, and RF phase control are required. Planned optical, RF, x-ray and electron beam measurements to characterize the dependence of electron beam parameters and synchronization on RF phase stability are presented.

I. INTRODUCTION

PLEIADES (Picosecond Laser Electron InterAction for Dynamic Evaluation of Structures) is a next generation Thomson scattering x-ray source being developed at Lawrence Livermore National Laboratory (LLNL). Ultra-fast ps x-rays (10-200 keV) are generated by colliding an energetic electron beam (20-100 MeV) with a high intensity, sub-ps, 800 nm laser pulse. Generation of sub-ps pulses of hard x-rays (30 keV) has previously been demonstrated at the LBNL Advanced Light Source injector linac, with x-ray beam fluxes of 10^5 photons per pulse [1]. The LLNL source is expected to achieve fluxes between $10^7 - 10^8$ photons for pulse durations of 100 fs to 5 ps using interaction geometries ranging from 90° (side-on collision) to 180° (head-on collision).

II. EXPERIMENT LAYOUT

The PLEIADES facility consists of a Ti:Sapphire OPCA laser system capable of producing bandwidth limited laser pulses of 50 fs with up to 1 joule of energy at 800 nm, an S-band photo-cathode RF gun, and a 100 MeV linac consisting of 4, 2.5-meter-long accelerator sections. The RF gun is driven by a picosecond, 1 mJ, UV laser that is synchronized to the interaction drive laser.

A schematic of the interaction region is shown in Figure 1. To maximize x-ray flux while minimizing effects of timing jitter, the laser incidence angle will initially be 180° (head-on collision) with respect to

electron beam direction, though a 90° degree interaction geometry will also be possible. The focal length between the final focus quadrupole triplet and the interaction region is 10 cm to allow for maximum focus strength and minimum electron bunch spot size. A 30-degree bend dipole magnet will be used to bend the electron bunch out of the x-ray beam path following the interaction. An off-axis 1.5 m focal length, parabolic mirror will be used to focus the laser to a diffraction-limited $15 \mu\text{m}$ FWHM spot size at the interaction point. A beryllium flat mirror placed in the x-ray beam path will serve as the final steering optic for the laser, while being transparent to the x-ray beam.

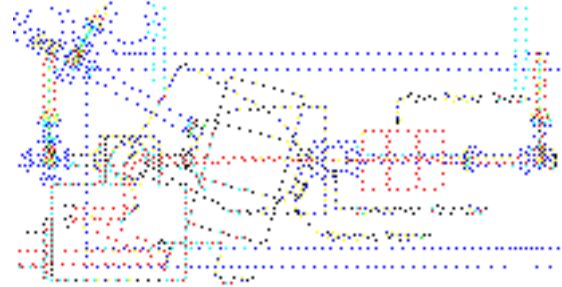


Figure 1: Interaction geometry

III. ELECTRON BEAM PRODUCTION

Initial experiments will focus on the generation of 30 keV x-rays produced in a head on collision using a 35 MeV electron beam. Simulations have been performed using PARMELA to optimize the beam production and transport. It has been shown that by injecting the 0.5 nC, 5 MeV electron beam produced by the RF gun into the first accelerating section sufficiently ahead of the peak accelerating phase, the bunch can be substantially compressed in time, from about 6 ps FWHM to about 1.7 ps FWHM. The subsequent accelerator sections can then be used to accelerate the beam to 35 MeV as well as remove some of the energy spread induced during the compression process. At the exit of the accelerator, the electron beam normalized rms emittance is about

3.5 mm-mrad, the rms bunch length is 0.7 ps, and the rms energy spread is 0.5 %. A spot size of 30 μm FWHM is obtained at the focus.

III. X-RAY PULSE PRODUCTION AND TIMING JITTER EFFECTS

The expected x-ray production was calculated and the effects of RF phase and timing jitter were determined by integrating the emissions probability per unit time, dN_x/dt , given by

$$\frac{dN_x}{dt} = \int n_y(\mathbf{x}, t) n_e(\mathbf{x}, t) d\mathbf{x}$$

where $n_y(\mathbf{x}, t)$ is the laser photon density, and $n_e(\mathbf{x}, t)$ is the electron density. The calculations were performed with a 300 mJ, 300 fs laser pulse in conjunction with the PARMELA output in place of $n_e(\mathbf{x}, t)$. Figure 2 shows the expected x-ray yield versus phase jitter of the linac for the cases where the electron beam is compressed in the first section (accelerated near the zero crossing), and not compressed (accelerated on crest).

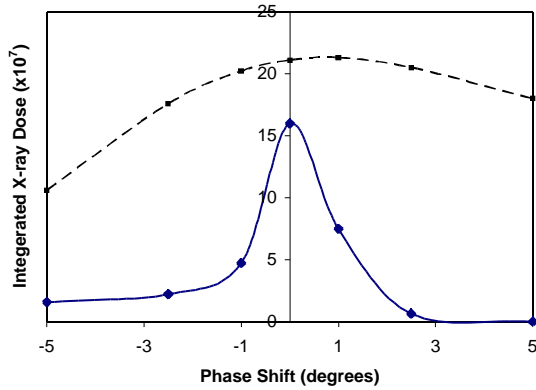


Figure 2: Simulated x-ray yield versus phase shift (Dotted: compressed beam. Solid: uncompressed).

It is seen that the phase jitter requirements for the compressed beam is less than one degree (or about 1 ps). Thus, picosecond phase and timing control will be required to maintain stability of the x-ray source when operated in the short bunch mode.

IV. BEAM CHARACTERIZATION

To date, the electron beam has been accelerated up to 60 MeV, and the emittance for a 300 pC bunch has been measured to be about 15 mm-mrad. Improvements in emittance are expected with improvements in the UV drive laser uniformity and optimization of the electron beam transport. Phase

jitter between the drive laser oscillator and the RF phase in the gun has been measured by mixing a 2.8 GHz microwave signal generated by the laser oscillator with the fields taken directly from the RF gun. This has shown short time scale (< 1 minute) phase stability of ± 1 degree.

Longer term phase drifts will be eliminated by a computer controlled feed back loop integrated with a direct measurement of the UV drive laser arrival phase in the RF gun and a voltage controlled phase shifter used to implement phase corrections. The direct phase measurement will employ a 20 GHz bandwidth, 800 nm optical fiber switch modulated by microwaves sampled from the RF gun to provide a nonlinear correlation between the gun fields and the IR laser pulse used to produce the UV photocathode drive laser.

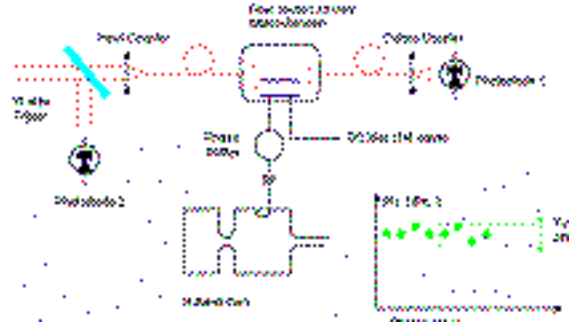


Figure 3: Direct phase jitter measurement.

V. CONCLUSIONS

The PLEIADES Thomson x-ray source facility will provide high brightness ($> 10^7$ x-rays/pulse), picosecond pulses for dynamic measurements in matter, including radiography, dynamic diffraction, and spectroscopy. Careful diagnosis and control of RF jitter and laser to RF timing will be required to produce stable picosecond to sub-picosecond x-ray pulses. Expected performance parameters and planned jitter measurements and control methods have been presented

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

- [1] R.W. Schoelein, et. al., "Femtosecond x-ray pulses at 0.4 Angstrom generated by 90 degrees Thomson scattering: A tool for probing structural dynamics of materials," *Science* **274**, 236 (1996).